Production and Isolation of ^{237}U and Fission Fragments Resulting from the $^{238}U(\gamma, n)$ and $^{238}U(\gamma, f)$ Reactions

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Objective

Photonuclear Production

- Predictive modeling
- Irradiation techniques
- Identification techniques
- Isotope purification
  - Chemical processes
  - Mass separation

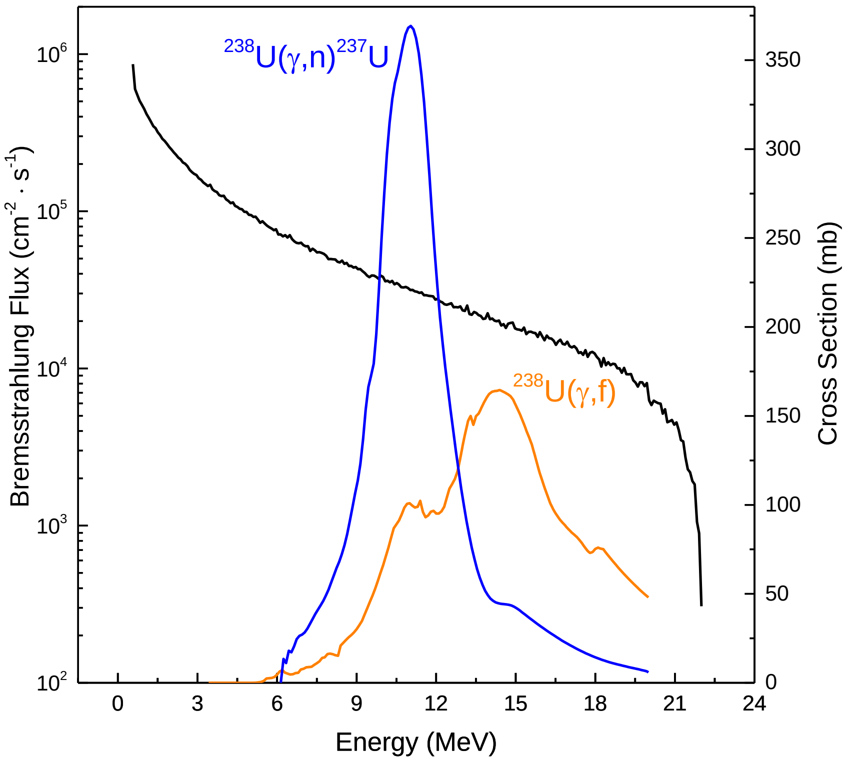
Demonstrate ^{237}U and fission fragment production from ^{238}U(γ,n) and ^{238}U(γ,f) reactions.

Radioisotope Uses

- Tracers
- Nuclear forensics
- Medical isotopes

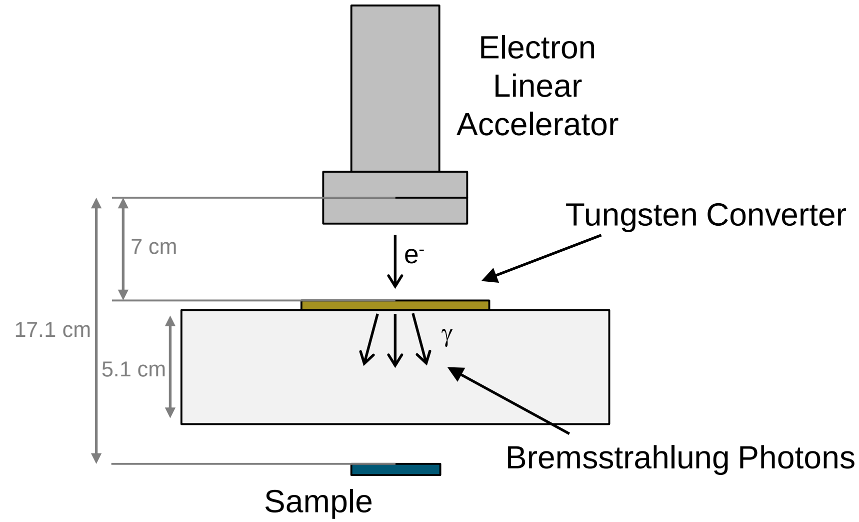
Photonuclear Production

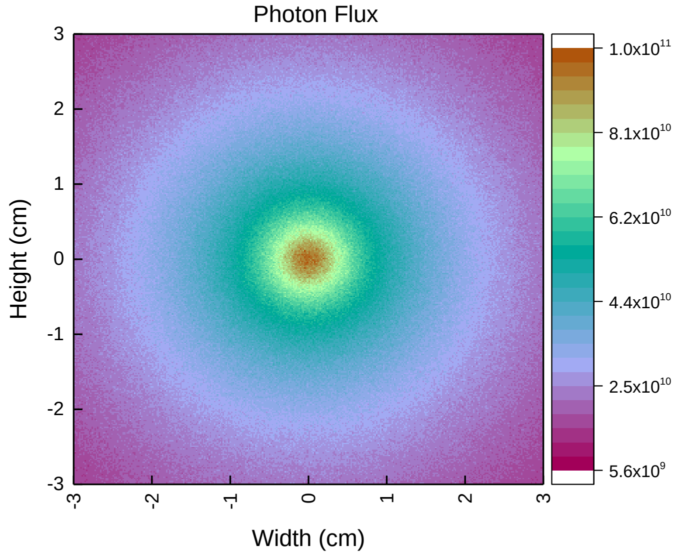
- Idaho Accelerator Center electron linear accelerator → tungsten converter → bremsstrahlung
- Bremsstralung curve simulated with MCNP6
- Cross sections obtained from the Evaluated Nuclear Data File
  - At the lower end of energies the production of ^{237}U is more likely
- Accelerator energy increase:
  - greater flux magnitude
  - higher photon endpoint energy
  - photons more forward directed



Predictive Modeling Using MCNP

- Help determine optimal experiment geometries
- Uranium foil fully positioned with in the beam diameter 10 cm from the converter
- Predict sample activity
  - Transport
  - Radiation safety
  - Production Yield
    - (ENDF/B-VII.1 (γ,n) cross section)
    - 1 hr. irradiation
    - 21.5 MeV
    - 0.1 g
    - ~90 μCi · kW^{-1} · hr^{-1} · g^{-1}

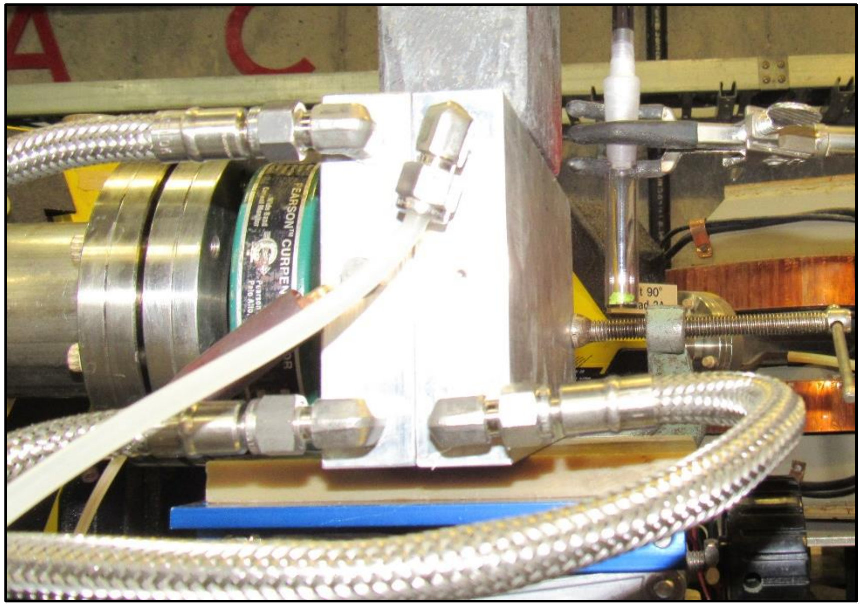


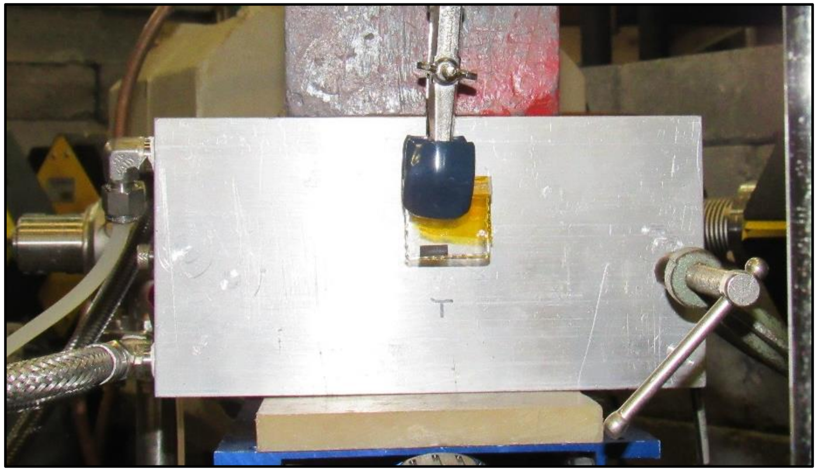


- ~50% within (-1,1)
- ~70% within (-2,2)
- ~85% within (-3,3)

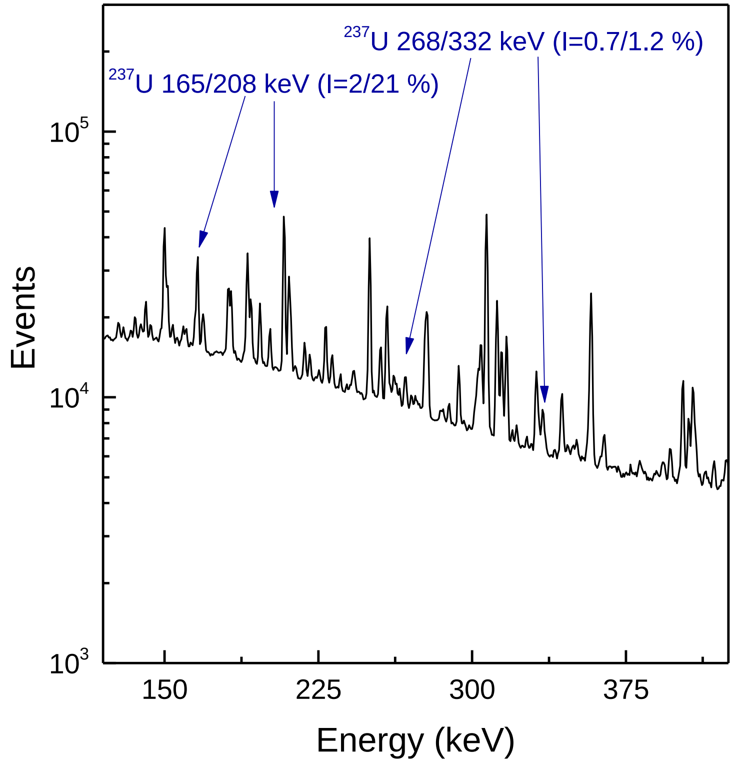
^{238}U Sample Irradiation

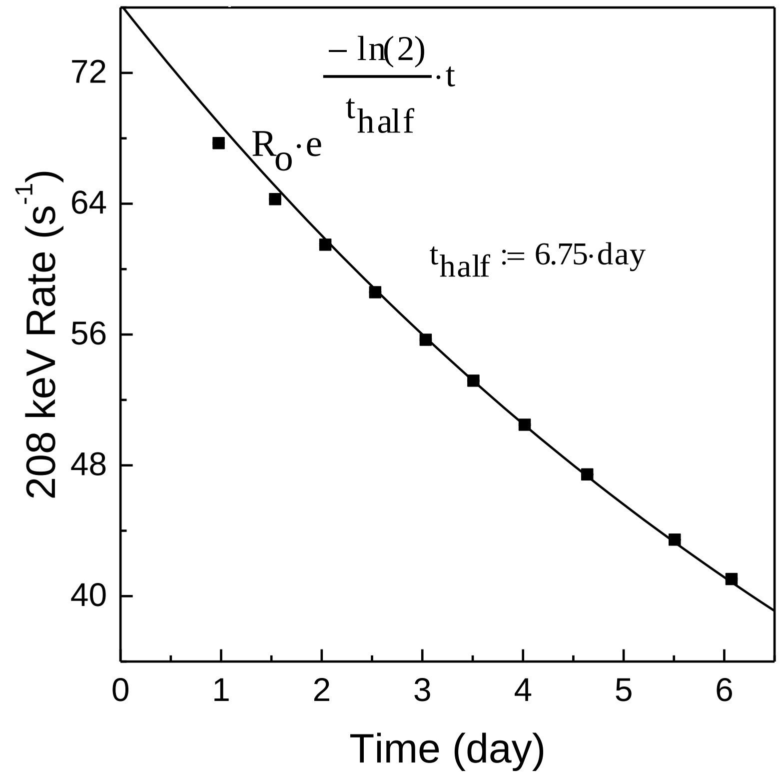
- Optimal accelerator energy
  - Stable 21.5 MeV
  - Endpoint energy beyond peak of cross section.
- Optimal accelerator current
  - Largest achievable
- Experiment parameters
  - 50 μA
  - 0.1 g ^{nat}U foil





Identifying ^{237}U





Detection Details

- 4 hrs. post irradiation
- 15 hr. detection

Cross Section Details

- $^{238}U(\gamma,n)$ Threshold: ~6.2 MeV
- Competes with $^{238}U(\gamma,f)$

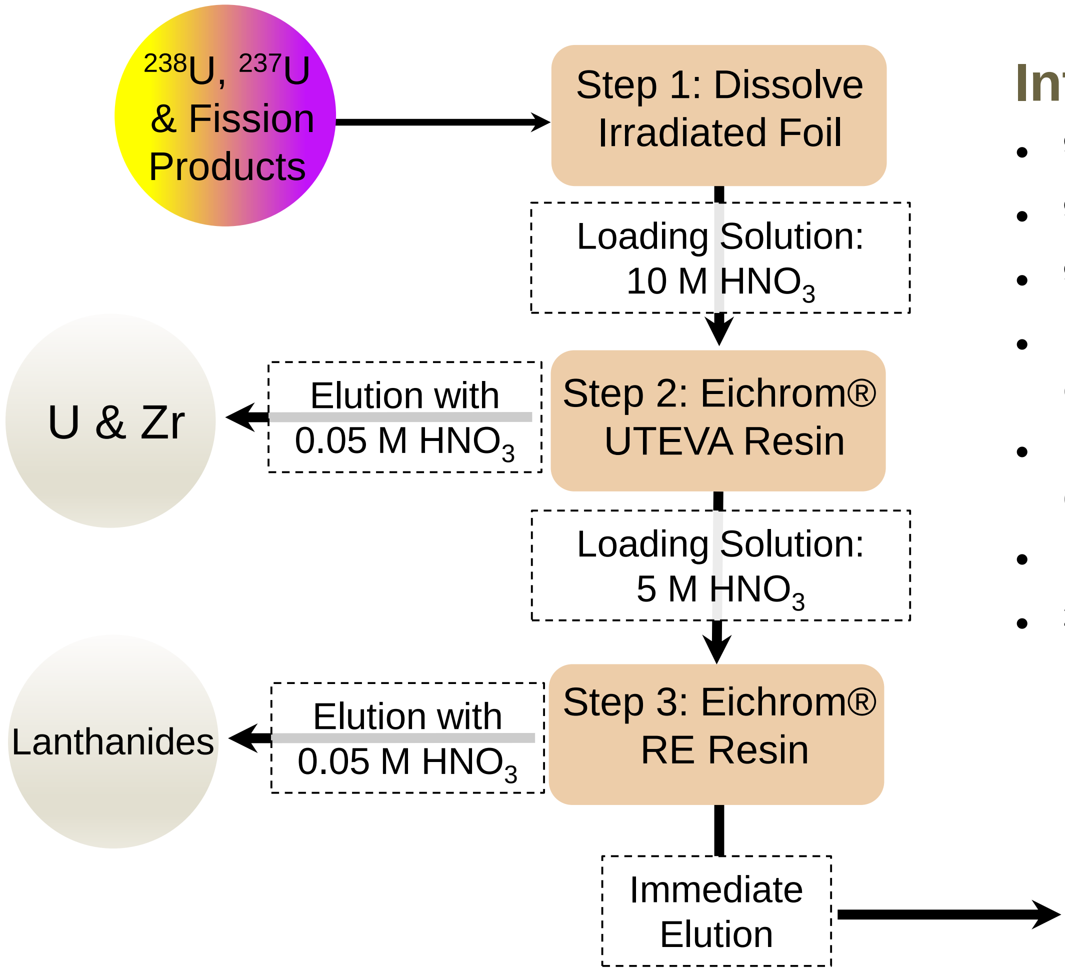
Identification

- Observed 4 photo-peaks (FP interferences)
- Data trends to half-life curve

Production Yield

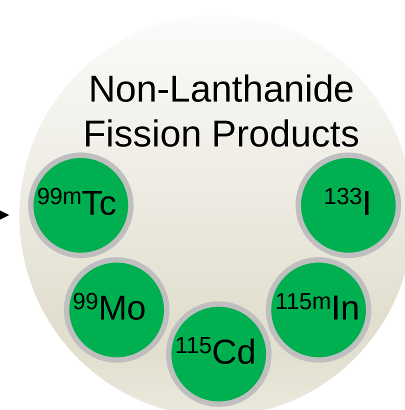
- ~98 ± 0.1 $\mu Ci \cdot kW^{-1} \cdot hr^{-1} \cdot g^{-1}$ (9% difference)

Chemical Separation at INL

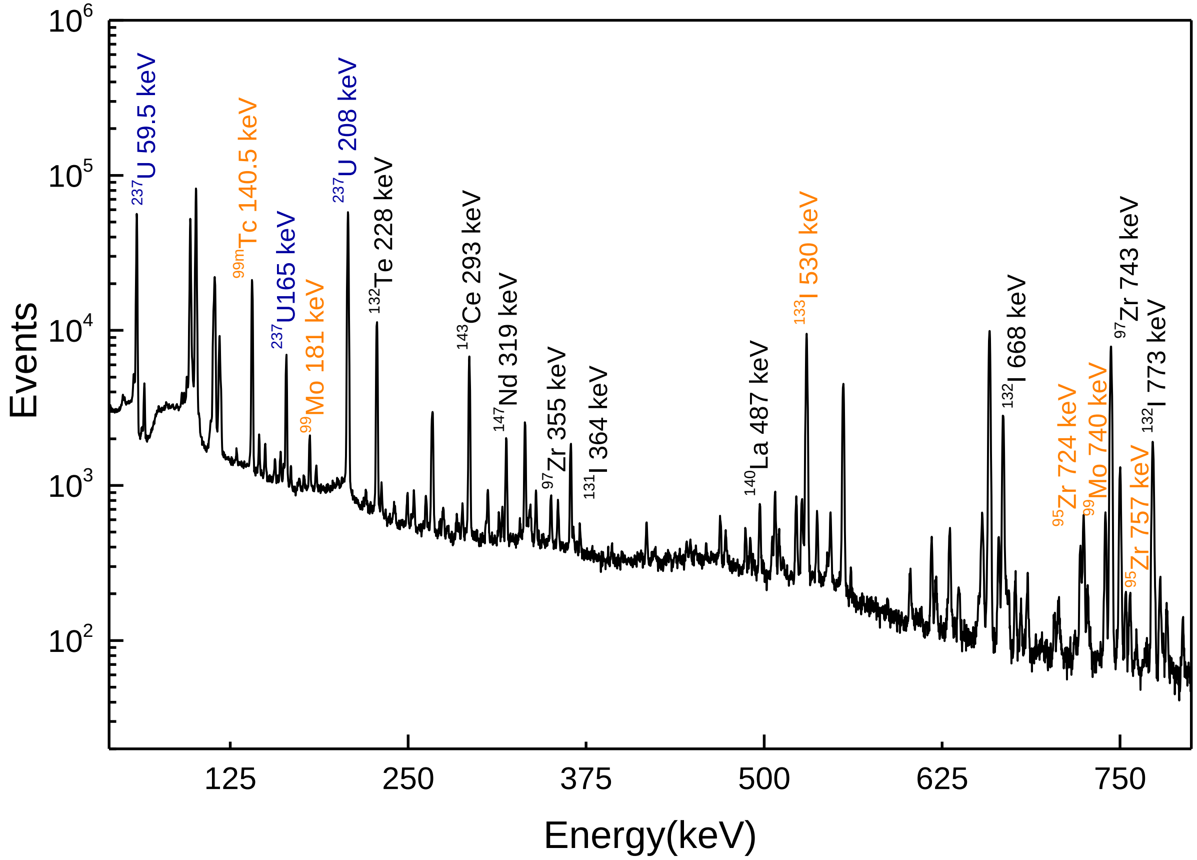


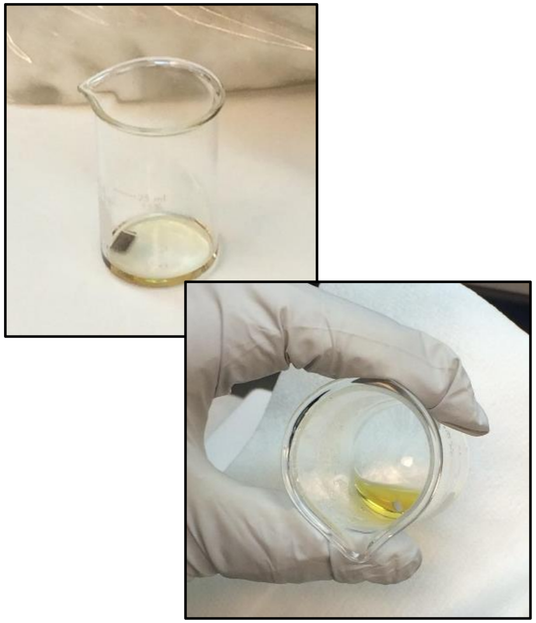
Interesting Isotopes

- ^{95}Zr – medical isotope
- ^{99m}Tc – organ imaging
- ^{99}Mo – decays to ^{99m}Tc
- ^{115}Cd – trace absorption and excretion of cadmium in tissues
- ^{115m}In – used to evaluate certain diseases
- ^{133}I – used to map brain tumors
- ^{237}U – trace uranium in ground water



Foil Dissolution

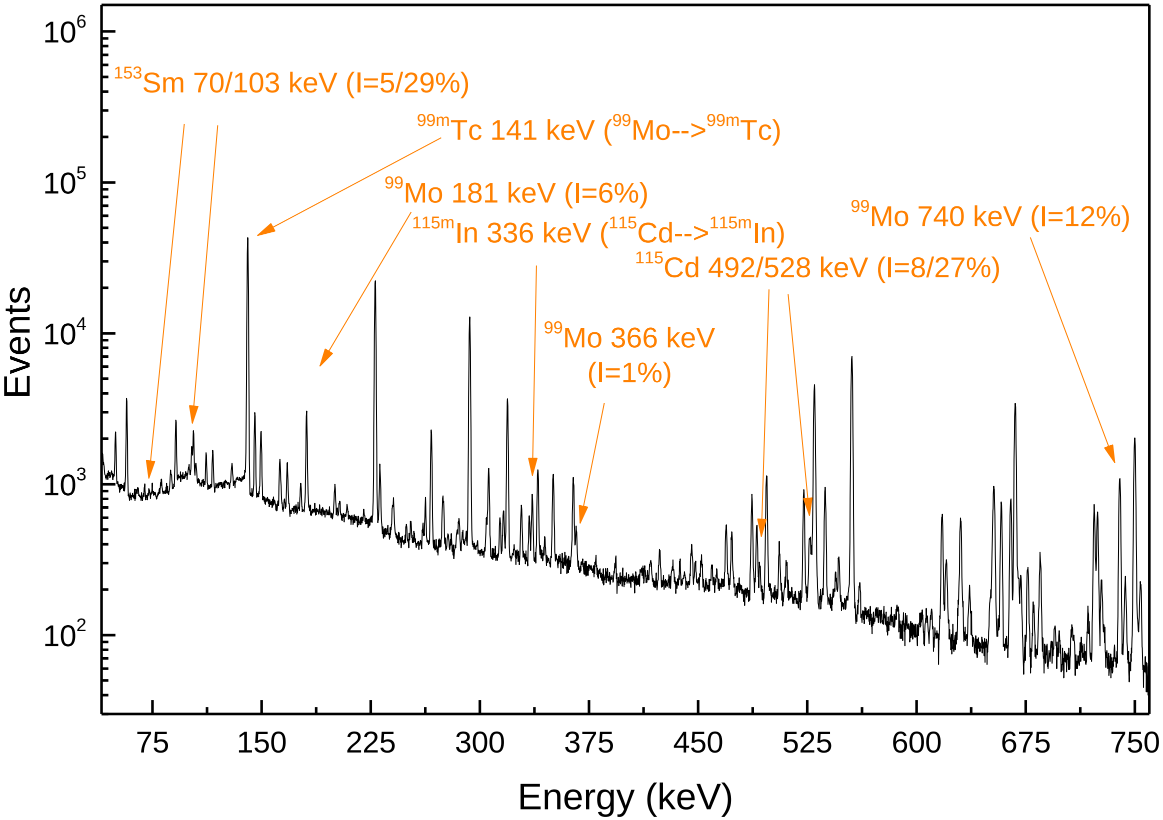




Dissolution Details

- ~1 hr.
- 10 M nitric acid

UTEVA Column



Half-lives

- ^{99}Mo – 2.8 days
- ^{99m}Tc – 6.0 hrs
- ^{115}Cd – 2.2 days
- ^{115m}In – 4.5 hrs
- ^{153}Sm – 1.9 days
  (cancer treatment/diagnostics)

Detection Details

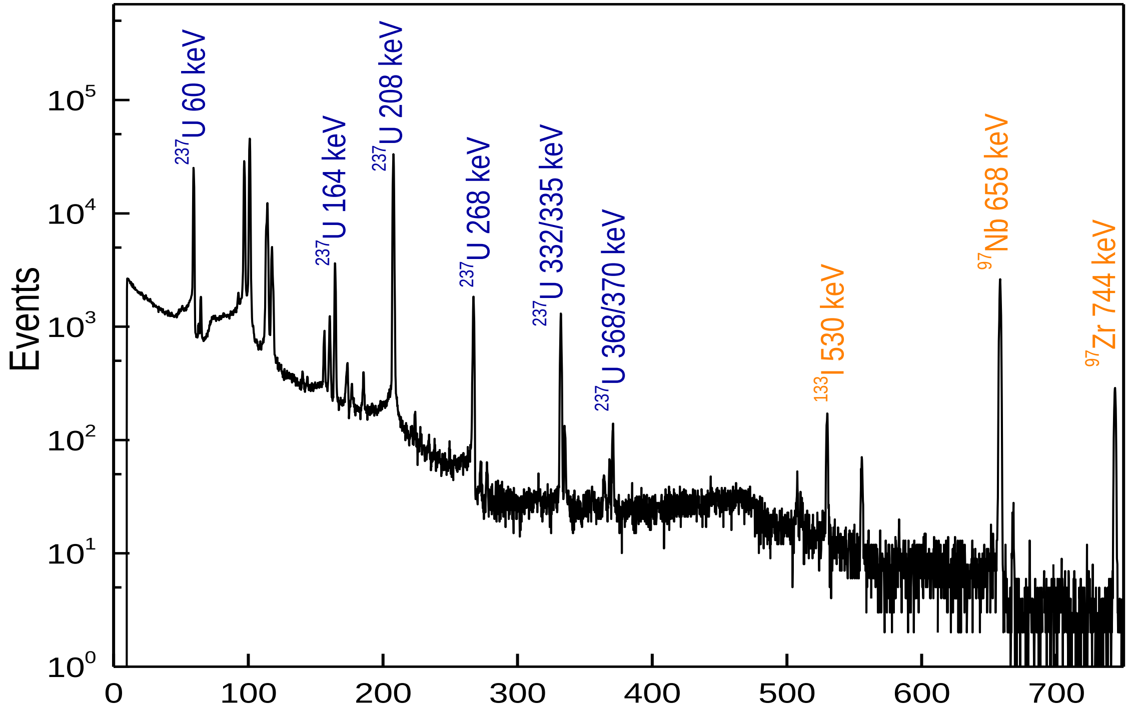
- UTEVA rinse
- 27.5 hrs. post irradiation
- 0.7 hr. detection

Elution from UTEVA Resin

Half-lives

- ^{237}U – 6.8 days
- ^{97}Zr – 16.7 hours

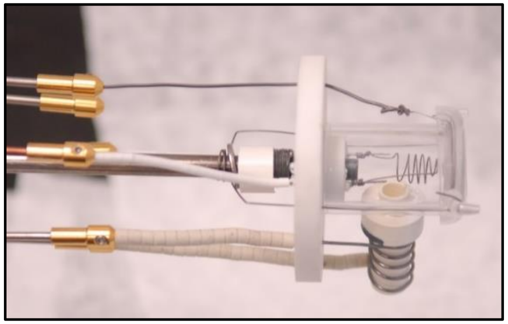
- ^{237}U most abundant radioisotope: ~ 6 days
- 87% of fission products with half-life < 1 day
  - 8% > 6 days

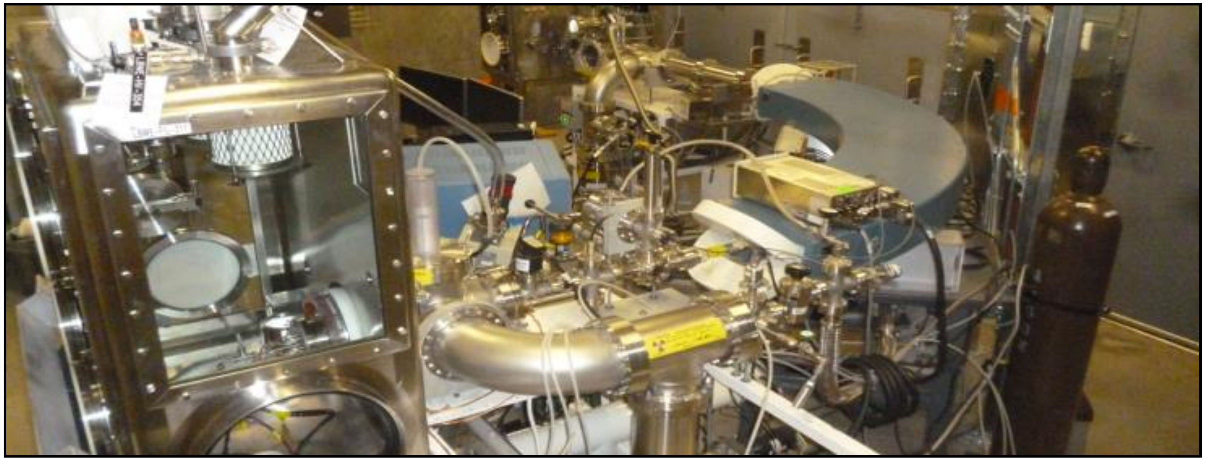


Detection Details

- Elution
- 26.3 hrs. post irradiation
- 30 minute detection

Isotopic Purification

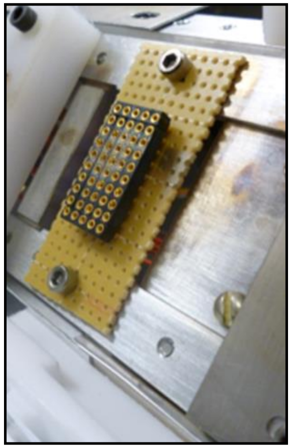


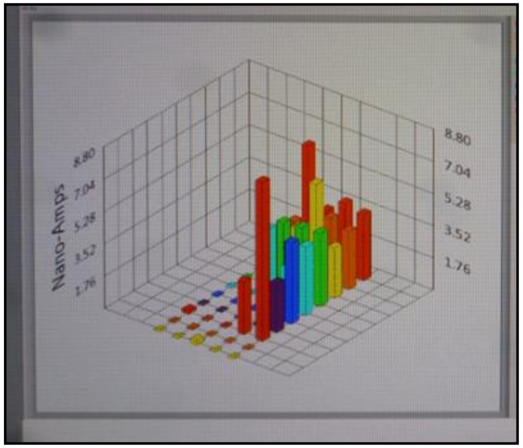


Mass separation

- Isotopes separated with mass separator
- The uranium sample is positively ionized thermally and by electron current
- Ion beam propagates through a bending magnet
- Lighter isotopes are deflected more sharply

Isotopic Purification





Catcher Foils

- Ion beams propagate into catcher foils
- 1% collection efficiency
- 5×10 Faraday cup catches charged particles used to determine the number of ions
- Pixel array readout characterizing the beam profile

Conclusions & Future Agenda

- Demonstrated photonuclear production of:
  - ^{237}U, ^{99m}Tc, ^{99}Mo, ^{115}Cd, ^{115m}In, ^{133}I, ^{153}Sm
- Optimize production and increase activities
  - Modify accelerator parameters
- Optimize sample transport
  - Goal under 3.5 hrs. for packaging and transport
- Optimize separation for isotopes of interest
  - Separation goals:
    - Uranium → 2.5 hrs.
    - Non-lanthanides in 3 hrs.
      - Strategy to optimize for each isotope of interest
    - Lanthanides < 7.5 hrs.
- Continue mass separator development
  - Optimize uranium separation
  - Introduce new radioisotopes

Thank you.